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# Life cycle cost analysis in building design

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LIFE CYCLE COST ANALYSIS
IN BUILDING DESIGN.

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# NAVAL POSTGRADUATE SCHOOL

Monterey, California

# THESIS

LIFE CYCLE COST ANALYSIS IN BUILDING DESIGN

by

Kenneth C. Kelley

December 1977

Thesis Advisor: J. C. Tibbitts

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life cycle cost analysis as applied to building operating cost savings, maintenance cost savings, and savings on replacement of building components and systems. Included is a discussion of the Economic Building Performance Model now used by the Western Division Naval Facilities Engineering Command, and current federal agency efforts to apply LCC concepts to building design.

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# LIFE CYCLE COST ANALYSIS IN BUILDING DESIGN

by

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# ABSTRACT

Life cycle cost analysis has been a part of good architectural design for many years. It has received even greater attention as the energy crisis makes it more clear that architects and owners must plan with greater emphasis on life cycle cost (LCC) versus initial construction cost. This thesis investigates the formulas and procedures currently used and illustrates life cycle cost analysis as applied to building operating cost savings, maintenance cost savings, and savings on replacement of building components and systems. Included is a discussion of the Economic Building Performance Model now used by the Western Division Naval Facilities Engineering Command, and current federal agency efforts to apply LCC concepts to building design.

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# I. INTRODUCTION

## A. PURPOSE OF THESIS

The purpose of this thesis is to investigate the process of life cycle cost (LCC) analysis as it is now being used by architects and engineers in the design of buildings.

## B. THESIS CONTENTS

Chapter Two presents a general definition of LCC as the summation of total building systems costs over the life of the building. When adjusted for the time value of money this summation is useful as an aid to making design decisions. The cost elements to be considered are discussed and the LCC model is introduced as a way of structuring an economic analysis of design alternatives.

Chapter Three reviews the mathematical formulas commonly used in economic analysis and relates them to the LCC model. Selection of a discount rate and treatment of inflation are discussed followed by an illustration of the process of discounting cash flows for LCC studies.

Chapter Four looks at recent experience with LCC in weapons systems development and current efforts to apply the model to building design.

The fifth and final chapter concludes that the usefulness of LCC can be improved by judicious development of a data base and a common format for analysis.

The appendices provide simple illustrations of the LCC process as applied to operating cost savings, maintenance cost savings, and savings on replacement of components and systems.

# II. ELEMENTS OF LIFE CYCLE COSTING

## A. INTRODUCTION AND OVERVIEW OF CHAPTER

This chapter defines life cycle cost as a summation of the total costs which accrue throughout the life of the building, as adjusted for the time value of money to enable useful comparisons to be made. Total costs of a building are recognized as being composed of several elements in addition to initial costs. LCC techniques are used with varying degrees of detail depending on the stage of building design being considered.

## B. GENERAL DEFINITION OF LIFE CYCLE COSTS

### 1. Summation of System Costs

The high cost of constructing a building gets a lot of attention from owners and designers alike. At every formal bid opening conducted by the government, or in every contract negotiation in the commercial area, there is concern over whether the construction can be done for the amount of money available. The owner , the designer, and the contractor all focus their attention on the initial cost to construct that building. But there is much more than that to be included in the cost of the building to its owner. The owner must pay the architect who designed the

building, and must pay the in-house planning staff for their front-end work in coordinating the work of the architects, the marketing consultants, the financial people, plus significant administrative costs during construction.

Once the building has been occupied the owner begins to receive its benefits but still incurs additional costs. Every year the owner must pay for lights and heat, taxes, and people to perform the functions the building is intended to shelter.

The life cycle cost of a building is the summation of all of the costs incurred for that building for all of the years from planning through ultimate sale or disposal.

### 2. Adjustment for the Time Value of Money

Any summation of costs for purposes of comparing alternatives cannot be valid unless the costs are in common terms. To be in common terms, the costs must be considered with respect to the timing of cash flows. The value of a dollar today is not the same as it will be one year from today for two basic reasons. First, inflation will affect the purchasing power of the dollar, meaning it will buy less goods and services a year from now. Second, the dollar received today has earning power. It can be invested for a real return over a span of time. In life cycle costing the principles of compound interest are used to compute present and future costs in a way that relates these two costs in common terms. The necessary formulas will be covered in some detail in Chapter 3.

### 3. A Decision Making Tool

Life cycle costing (LCC) is much more than merely the application of compound interest formulas. LCC is a technique, a procedure, a set of rules, a methodology, a systematic procedure by which a complex task is accomplished. The technique has been developed to allow its user to evaluate the results of a decision or to choose between alternatives as a part of making a decision. It does not provide an automatic decision but it gives added visibility to the cost elements of an investment decision.

### 4. Increasing Significance of LCC

Life cycle costing is gaining increasing significance to building designers and owners. The continuing effects of inflation on all building costs and the even faster escalation of energy costs call attention to the limitations of basing decisions solely on initial investment costs. There is a need to anticipate growth and changes in the use of buildings. It is becoming more widely recognized that the design of a building has long term effects on the operating cost of the building. Tradeoffs between initial costs and long term operating costs have always been considered by informed owners but today such tradeoffs are being given more attention and more visibility. The additional visibility provided by LCC techniques is important because with advances in technology the elements of costs and their interrelationships are getting more and more complex.

## C. THE REAL COSTS OF A BUILDING

The real cost of a building can be considered in terms of the initial cost, recurring costs on an annual basis and intermittently through the life of the building, and functional use costs. The total cost of ownership includes the sum of all costs. It can be shown that initial costs are a suprisingly small portion of total ownership costs.

### 1. Initial Costs

Initial costs are primarily the cost of construction. Other types of initial cost such as design and other owner costs are related directly to the construction cost. Interim financing costs are also incurred during construction, again related directly to construction costs.

The construction costs are composed of many elements. The common basis of breaking down costs has for years been in terms of materials, trades, or subcontract packages. The most familiar format has been the 16 division Uniform Construction Index (UCI). A more recent trend, of value in the conceptual and design development phase, has been the functional system and subsystem approach. This method separates the building into its elements from a functional standpoint such as foundation system, wall systems, roof systems, and mechanical systems.

Thinking of a building in terms of systems helps in understanding the interrelationships that can affect the initial cost of construction. A heavier wall system for

example may require a more substanial foundation system. A more energy efficient roofing system may permit a smaller heating or cooling system. The effect of one design decision on other aspects of the building can be studied in terms of building systems and the sum of costs for each of these systems will be the initial construction cost for the building.

### 2. Recurring Costs

The recurring costs for a building can be essentially the same each year or they can vary considerably over time. Types of recurring costs are as follows.

#### a. Operating - Utility Costs

Operating costs depend on how the building has been designed and how it is used by the occupants. The climate has an obvious effect on the heating and cooling requirements. The function to be performed in the building may serve to reduce operating costs by providing much of the heat required (an auditorium) or may increase operating costs (cooling a computer room in a hot climate).

The interaction between functional systems can be used in the design development to evaluate tradeoffs on a life-cycle basis. For example, the lighting system might be used to provide some of the heat required in the building.

#### b. Maintenance

The cost of maintenance is a serious

consideration in life cycle costing. Some materials look good when new and perform their function well but require extensive maintenance on a daily or weekly basis. Some mechanical systems depend on sophisticated control systems which work well only if continually tuned or adjusted. Other systems may be more expensive initially but work well for years with no attention.

c. Replacements

The components of various systems within a building do not last forever. Some, such as foundation systems may last as long as the building , but others, such as the roof system, may require replacement one or more times during the life of the building. Mechanical systems need occasional replacement of component parts such as pumps or fans. Some functional equipment may require replacement with newer and more efficient models. Sometimes the basic use of the building will change and the original mechanical equipment will be replaced with equipment of larger capacities. These possibilities must be considered in the life cycle cost analysis.

d. Alterations

Alterations of a building are practically inevitable. Even if the form perfectly fits the function on the first day of occupancy, changes will be desired soon afterwards. The dynamic nature of activities being performed create a necessity for alterations every year. It is hard to evaluate what alterations might be made but in some types of buildings there has been enough experience with routine alterations that a reasonable estimate of probable costs and consequences can be made. In any case,

where the need for future alterations can be reasonably predicted, they should be included in the life cycle cost analysis.

e. Functional Use Costs

Functional use costs can be considered separately from the facility operational costs. The function of a building might be to provide health care services. This function would require doctors and nurses and certain specialized equipment. Such functional uses must be considered by the owner when he is evaluating his overall investment. From the designers point of view only changes in functional costs need be considered. If the decision at hand is whether to use gas or electric heat, the number of nurses to be employed is not relevant. If a decision on building layout requires an additional nurses station to serve the same number of patients, the functional cost of the additional nurses station must be included in evaluating the alternatives.

3. __Total Cost of Ownership__

The relative significance of initial construction costs versus the total cost of ownership can be seen in an example of a hypothetical office building. This example has been taken from the private sector so the impact of financing on the total cost of ownership can be shown [Ref.1]. For a federal project there is no visible financing charge but rather an imputed opportunity cost for investing in the project.

The following example is based on a hypothetical office building of 100,000 square feet (SF) constructed at a

cost of $50/SF. Design and other owner costs are estimated at 10% of construction cost with an additional 10% interim financing cost, bringing the total initial cost to $600,000. For the years after initial construction, operating and maintenance costs are estimated at $2/SF over a life of 40 years. Cyclical renewal costs are estimated at $250,000 every eight years. The total amount financed was $6,000,000 at 8% for 40 years for a total interest cost of $14,000,000. These costs are listed in Table II-i and illustrated graphically in Figure 2-1. The time value of money is disregarded in this example for the purpose of simplification.

HYPOTHETICAL OFFICE BUILDING

| | | |
|---|---|---|
| Initial Project Development Costs: | | |
| Initial Construction | | % of LCC |
| 100,000 SF at $50/SF | $5,000,000 | 17.24 |
| Design and other owner costs | $500,000 | 1.72 |
| Interim financing costs | $500,000 | 1.72 |
| Subtotal Initial Costs | $6,000,000 | 20.68 |
| | | |
| Continuing Project Costs: | | |
| Operating and maintenance cost | | |
| $2/SF/YR for 40 years | $8,000,000 | 27.59 |
| Cyclical renewal cost | | |
| $250,000 every 8 years | $1,000,000 | 3.45 |
| Financing cost | | |
| interest cost for a decreasing principal mortgage of $6,000,000 at 8% for 40 years | $14,000,000 | 48.28 |
| Subtotal Continuing Costs | $23,000,000 | 79.31 |
| | | |
| Total Life Cycle Facility Cost | $29,000,000 | 100.00 |

Table II-i

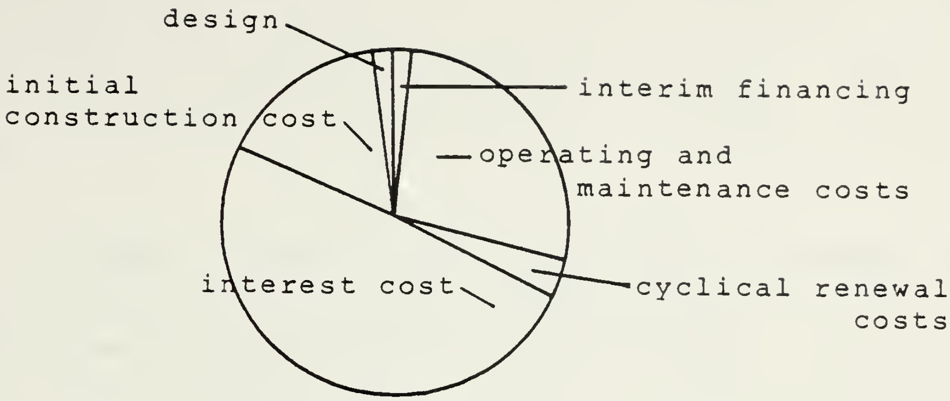



Figure 2-1

This example excludes the cost of land, the owner's functional use cost, and any salvage or disposal costs at the end of 40 years of building service. The impact of these items is highly variable but tends to further reduce the percentage of life cycle cost attributable to initial construction costs. It should be observed that the designer should strive for minimal operating and maintenance costs, since they are a significant portion of the total cost.

## C. LIFE CYCLE COST MODEL IN DESIGN ANALYSIS

Life cycle cost modeling is one of a variety of techniques often used for performing cost studies under the broader term of economic analysis. With respect to building design, the Naval Facilities Engineering Command (NAVFAC) divides economic analysis into discrete types according to the purpose of the analysis [Ref. 2 ]. The broadest type is the Fundamental Planning Analysis (FPA). The FPA is directed at the facilities planning objective. That is, given that a mission function is to be performed, the FPA seeks the optimum method of satisfying the requirement. The

solution may or may not turn out to include a military construction project and planners should consciously resist the temptation to merely use the FPA to justify a decision to build. The analysis should lead to a decision and not vice versa.

FPA is further divided into two types, primary and secondary. The primary FPA addresses itself to the basic need and economic justification for some change to present conditions, the justification being in terms of absolute cost savings. A secondary FPA is used once a deficiency or changed requirement for a facility has been identified. In essence, given the requirement for a facility, the most economic means of satisfying the requirement must be determined. It is recognized that the facility will cost money and the least-cost alternative is sought.

The second broad type of economic analysis with respect to building design is referred to as Design Analysis (DA). The DA is used once the decision has been made to build. It is an economic analysis of design alternatives. The DA is essentially the same thing as the FPA except that DA addresses design alternatives and FPA addresses planning alternatives. The FPA is usually prepared by the Navy activity as a part of the Facility Study (DD Form 1391C) supporting a request for approval of a military construction project. The DA is usually done by the architect as a part of the project design documentation.

Life cycle costing in building design as discussed in the thesis is primarily concerned with the DA type of economic analysis. LCC focuses not just on the initial economics of various design alternatives but on the implications those alternatives have on long term costs. The purpose here will be to explain the life cycle cost model as a technique for design economic analysis.

Application of the model will be illustrated with some examples taken from recent military construction projects and some examples constructed specifically to illustrate possible applications. The examples will cover components of a building. A thorough LCC study for a design project may include detailed analysis of only one building component or of a multitude of components depending on the judgment of the designer in a particular situation.

# III. LIFE CYCLE COSTING TECHNIQUES

## A. INTRODUCTION AND OVERVIEW OF CHAPTER

This chapter reviews the basic mathematics of compound interest and relates the basic concepts to the LCC model. Since the Department of Defense (DOD) specifies the use of a 10% discount rate, the origin of that discount rate is discussed. The treatment of normal inflation and differential inflation now being experienced in the field of energy is reviewed next. Then the process of discounting cash flows is illustrated using cash flow diagrams and a table of computations which will serve as a model for further illustrations in the appendices. The chapter concludes with comments on peculiar problems associated with estimating costs for use in a LCC model.

## B. THE TIME VALUE OF MONEY

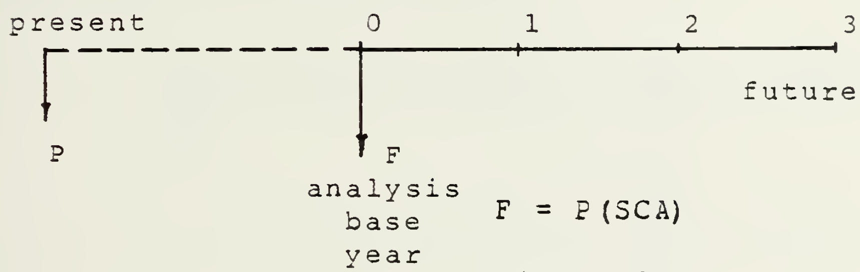
The mathematics of compound interest is the foundation of life cycle cost analysis. The subject is addressed in detail in various texts on management and engineering economy. References 1 and 3 have been used in the preparation of this section. This section is intended as a brief review of those concepts, a refresher to help in the understanding of following sections.

1. Single Compound Amount Factor (SCA)

The basic formula from which all the following formulas can be derived is the single compound amount formula. If a principal amount, P, is invested for n years at an annual rate of interest, i, it will be worth a future amount, F, as a result of compounding.

$$F = P(1+i)^{n} \tag{1}$$

The factor, $(1+i)^{n}$, is called the Single Compound Amount factor (SCA) by Ref. 1 . In LCC the SCA factor is used for projecting costs forward in time from the present time to the start of the analysis zero year.




F = P(SCA)

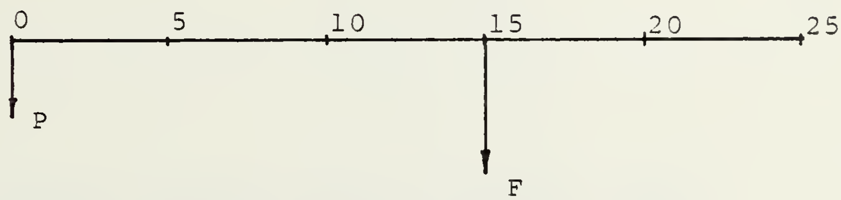
Figure 3-1

## 2. Single Present Worth Factor (SPW)

The problem of simple compounding can be reversed to find out what principal, P, must be deposited now so that by earning interest at an annual rate of interest, i, it will increase in value to a future amount, F. The terms are the same as equation (1) but instead of solving for F, we solve for P.

$$P = F \bullet \frac{1}{(1+i)^n} \tag{2}$$

The factor $1/(1+i)^n$ is called the single present worth factor (SPW). In LCC the SPW factor is used for bringing costs back from some future amount to a present value as of the base period.




P = F(SPW)

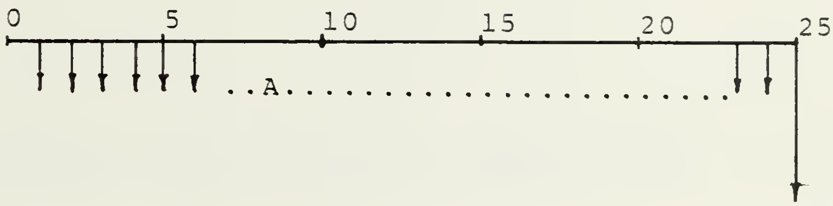
Figure 3-2

## 3. Uniform Sinking Fund Factor (USF)

Often it is necessary to accumulate money to meet some future expense. To determine what annual amount, A, must be deposited at the end of each year for n years, earning an annual interest rate of i, in order to produce a future amount, F, the following formula would be used.

$$A = \frac{F \bullet i}{(1+i)^n - 1} \qquad (3)$$

The factor $i/((1+i)^n-1)$ is called the uniform sinking fund factor (USF). In LCC applications the USF factor is used for converting some future cash flow to an equivalent uniform annual cost (EUAC). For example, if a building must be removed from leased premises at the end of the lease the cash flow can be considered as a future one time cost or as an equivalent series of uniform cash flows over each year of the lease.




A = F(USF)

Figure 3-3

4. <u>Uniform Capital Recovery Factor (UCR)</u>

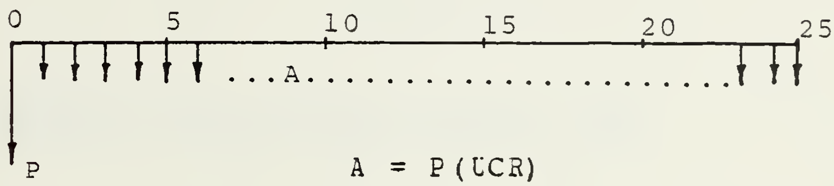
It is often desirable to know what annual amount, A, can be earned for n years from a principal investment, P. This can be found by substituting in equation (3) the value given for F in equation (1).

$$A = P(SCA)(USF)$$

$$A = P(1+i)^n \bullet i/((1+i)^n - 1)$$

$$A = \frac{Pi(1+i)^n}{(1+i)^n - 1} \qquad (4)$$

The factor $\frac{i(1+i)^n}{(1+i)^n - 1}$ is called the uniform capital recovery factor (UCR). In terms of LCC the UCR factor is used for converting some present cash flow to an equivalent uniform annual cash flow. The initial investment P is mulitplied by the UCR factor to obtain the EUAC. Conversion of costs to EUAC is sometimes useful in comparing alternatives of different economic lives.




$$A = P(UCR)$$

Figure 3-4

5. <u>Uniform Compound Amount Factor (UCA)</u>

The formula for uniform sinking fund (USF), equation (3), can be reversed. If the annual amount, A, to be invested at the end of each year for n years is known, the future amount, F, can be found by solving equation (3) as follows.

$$F = \frac{A}{(USF)}$$

$$F = \frac{A(1+i)^n - 1}{i} \qquad (5)$$

The factor $\frac{(1+i)^n - 1}{i}$ is called the uniform compound amount factor (UCA). In LCC this UCA factor could be used for converting a series of uniform annual costs to an equivalent single cost at some future point in time. This would be be applicable in the case of a long lead time

before the base period for analysis. An owner might have to pay annual taxes on his property for a period of several years before construction is complete and benefits start to accrue.

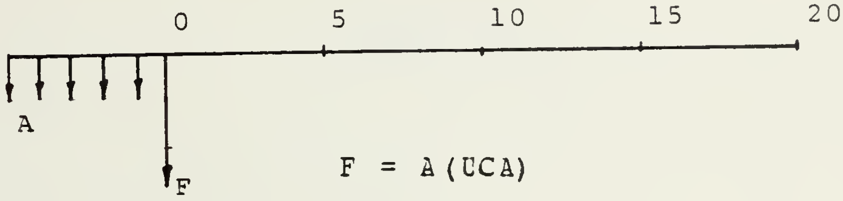



Figure 3-5

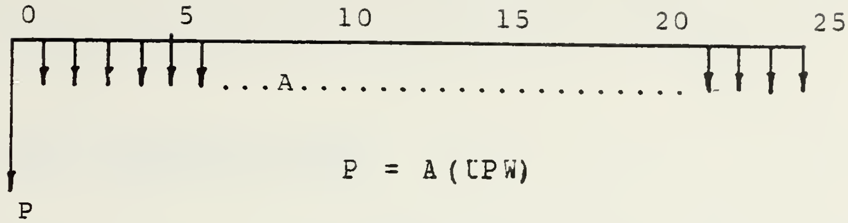
6. Uniform Present Worth Factor (UPW)

The formula for uniform capital recovery, equation (4), can be similarly reversed. If the annual uniform payment, A, is known, the present principal value, P, of those payments can be found by solving equation (4) as follows.

$$P = \frac{A}{(UCR)} \qquad (6)$$

$$P = \frac{A(1+i)^n - 1}{(1+i)^n}$$

The factor $\dfrac{(1+i)^n - 1}{i(1+i)^n}$ is called the uniform present worth factor (UPW). In LCC the UPW factor is used for coverting a series of uniform annual costs to an equivalent single cost at the present time. Annual maintenance costs are commonly converted to present value by multiplying the annual cost times the UPW factor.




$$P = A(UPW)$$

Figure 3-6

## C. SELECTION OF DISCOUNT RATES

The compound interest equations are often explained with the factor i represented as the annual rate of interest, a financial relationship between a borrower and a lender. A more general interpretation of i is the rate of return required by the investor. There are several approaches to determining the rate of return, depending on the investor's own situation. It may be best in some firms to use the opportunity cost of investments foregone when the capital budget is limited to internally generated funds. In competitive industry the weighted average cost of debt and equity capital might be chosen as the most appropriate rate. A rate slightly higher than a regulated "fair rate of return" might be used by a public utility company. Chapter 11 of Ref. 3 contains a good discussion on choice of a minimum attractive rate of return.

### 1. Commercial Discount Rates

In the commercial area no real benchmark has been established for the discount rate to be used. Each analyst or firm seems to arrive at its own appropriate rate to be used. The rates commonly used range from 8% to 13% with some higher than that. A firm with a limited capital budget

and several very promising investments proposed might easily find a cut-off rate of return at 20% or higher.

### 2. DOD's Discount Rate

Agencies of the federal government have faced many different arguments about what discount rate should be used. Some engineers argued for a zero interest rate for projects financed out of current taxes, while others argued for an interest rate equal to the rate paid on public borrowing. Still others supported an opportunity cost approach. These varied views led to diverse practices in federal government agencies which were described and criticised in hearings before the Subcommittee on Economy in Government of the Joint Economic Committee of the Congress in 1968. These disagreements have now been resolved with release of the following documents.

#### a. Stockfish Paper

The concept of opportunity cost now prevails in the federal sector. This concept was explained in a paper entitled "Measuring the Opportunity Cost of Government Investment", IDA Research Paper P-490, March 1969, by J. A. Stockfish. Stockfish worked on determining an average rate of return on private investment capital and arrived at an overall weighted average composite rate of return of 12% for the years from 1949-1965. This nominal rate of return was reduced for inflation by netting out the 1.6% average annual consumer price increase over the period considered. The conclusion was that money spent for government investments would divert funds from the private sector that could be invested for a real rate of return of about 10.4% [Ref.2].

b. OMB Circular A-94

Based on the Stockfish paper, and presumably many other convincing arguments in favor of the opportunity cost approach, the federal government has selected a discount rate of 10% to be used in economic evaluation of investments. This rate is specified by OMB Circular A-94 and by DOD Instruction 7041.3. The use of this specified discount rate has enabled projects to be compared on an equal basis without the distortions inherent in each department deriving its own rate. Interest tables based on this rate have been published in DOD directives and used by all services.

3. Impact of Inflation

a. Inflation-discount Spread

Some higher rates of return are "nominal" rates which include both the effects of inflation and the real earning power of money. When "nominal" rates are used operating costs for the future must first be escalated at the assumed inflation rate and then discounted back to present value using the "nominal" rate of return. Some analysts take the position that interest rates and inflation increase and decrease in a parallel fashion with interest rates consistently staying about 3% above the inflation rate. In that case the selection of any "nominal" rate and a corresponding escalation rate is considered acceptable as long as the spread between the two is kept at 3%. The 10% discount rate used by DOD is a "real" rate of return where the effects inflation have been removed. In some situations

however, such as energy analysis, additional inflation must be considered.

b. Differential Inflation

The 10% real rate of return specified by OMB assumes that a normal amount of inflation strikes all alternatives and cash flows uniformly. However, in some specific cases the analyst will have firm justification for using an inflation rate in excess of the inflation rate of the general economy. The DOD policy regarding such an analysis is to split the study into two phases. The first phase would use prices in terms of constant dollars using the standard 10% discount rate. A second phase of the study would consider the differential inflation.

Since a normal amount of inflation has already been considered via the 10% discount rate, only differential inflation should be considered in the second phase. In other words, if fuel costs are expected to rise at 8% and the general economy is expected to inflate at 5%, only the 3% differential inflation rate should be used. Fuel costs should then be projected to each future year (n) by compounding according to the formula $F = P(1+.03))^n$. That future amount F should then be discounted back to the base period according to the formula $P = F/(1+.10)^n$. The inflation and discounting can be done in either order or both at once by use of interest tables constructed for that purpose. The tables provided by Ref. 2 for this purpose have been used in this thesis.

## D. DISCOUNTING CASH FLOWS - EXAMPLES

### 1. Cash Flow Diagrams

The relationship between cash flows in a life cycle cost analysis can often be clarified by use of a cash flow diagram. In these diagrams the timing of cash flows over the years under consideration are represented on a horizontal time scale.


Figure 3-7

The cash flows occuring over the years are represented by arrows drawn at the appropriate point in time. Costs will be represented as downward arrows and benefits will be represented as upward arrows.

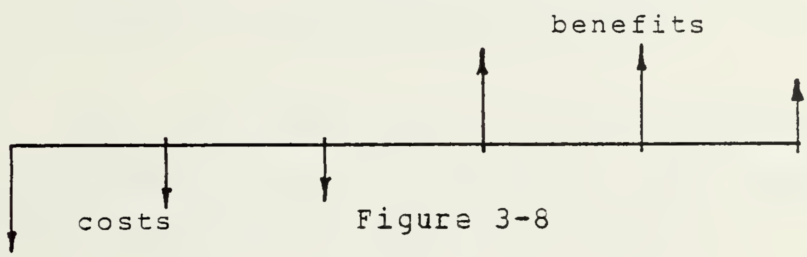



Figure 3-8

The costs and benefits are then listed in tabular form for computations to convert them to the common base year for analysis. Any year can be chosen as the base year for analysis but the most common practice is to convert both costs and benefits to their corresponding value as of the present time. The following is a brief example to illustrate the format to be used in following chapters.

Assume that an energy conservation project will cost $10,000 today. It will need a repair or replacement of parts at the end of the fifth year costing $500, and will save $1,200 in fuel costs for the ten years of the study. The net present value (NPV) of these cash flows can be determined as follows, in order to determine the feasibility of the project [Ref. 4 ].

a. Initial Investment

The first cash flow is the investment cost of $10,000. This cost occurs at the beginning of the project so it is already in present value terms.

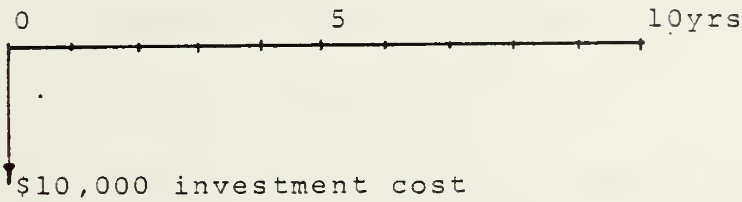



Figure 3-9

b. Repair or Replacement of Parts

The next cash flow we will consider is the $500 cost of replacement parts in year five. The cash flow is considered to occur at the end of the year.

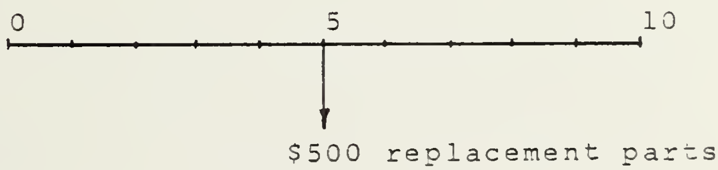



Figure 3-10

The $500 future cost must be converted to present value by multiplying by the appropriate single present worth factor (SPWP = $500(SPW, i=10%, n=5)

$$P = \$500(0.6209) = \$310$$

SPW was computed from equation (1). The \$500 cost can then be considered equivalent to a \$310 cost occurring at the present time.

c. Annual Fuel Savings

The last cash flow is the series of benefits due to the fuel savings. These benefits are shown as arrows above the horizontal time line. Again the cash flow is considered to occur at the end of each year.

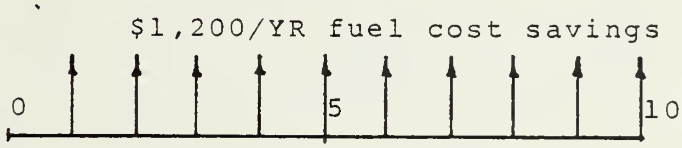



Figure 3-11

The uniform future benefits must be converted to present value by multiplying by the appropriate Uniform Present Worth factor.

$$P = \$1,200(UPW, i=10\%, n=10)$$

$$P = \$1,200(6.144) = \$7,373$$

In this case it was assumed that the fuel costs did not inflate any faster than the general economy. UPW was computed from equation (6).

d. Discounted Net Cash Flows

Computations are summarized in the following format.

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial investment | $10,000 | | 1.00 | $10,000 |
| 5 | replacement parts | 500 | | .621 | 310 |
| 1-10 | annual fuel savings | | ($1,200) | 6,144 | (7,373) |
| | | TOTAL NPV COST | | | $2,937 |

Table III-1

2. <u>Discussions</u>

Most of the focus in LCC analysis is on costs. For this reason it is more convenient to use positive numbers for costs and consider any benefits as negative costs. Benefits are thus shown in parentheses in the tabular format. In this example the sum of all the discounted costs is positive indicating that the costs have exceeded the benefits and the project does not generate a 10% return on the investment.

Computation of the discount factors from the equations is often considered inconvenient. Traditionally tables of discount factors have been used to eliminate the

need for complex computations. The use of the tables can be explained in textbooks rather easily with appropriate emphasis on application of the principles of compound interest rather than on deriving of formulas. The tables of discount factors most commonly used for economic analysis within NAVFAC were published in Ref. 2.

It should be noted that there is a difference between the present value factors given in the tables of Ref. 2 and the factors obtained by using the formulas discussed earlier. That difference is because of a choice between two conventions for modelling cash flow. The most common convention is the end-of-year convention. This convention assumes that cash flows occur at the end of each interest period and the period is assumed to be one year. This annualizing convention is taught in basic accounting and engineering economy courses.

The second convention used is the uniform flow convention [Ref. 5, App. A]. This convention recognizes that many types of cash flow do not occur at only one point in the year. Interest payments may occur semi-annually, taxes might be paid quarterly, utility bills might be paid monthly, wages might be paid bi-weekly or weekly, and a variety of receipts or disbursements might occur daily or even more often. At the opposite end of the spectrum from the annual period is the assumption of an infinite number of small periods and the continuous compounding of interest. Continuous compounding usually requires more detailed explanation in presentation of economy studies so annual compounding is more commonly used for reference. The uniform flow convention is explained by Ref. 2 as the average discount factor. It happens that the average of two consecutive end-of-year factors is the same as the factor obtained when using continuous compounding in the uniform flow convention [Ref. 3 and 5]. Neither convention matches

perfectly to real life cash flow situations although there are many arguments that the uniform flow convention is closer to reality. The most accurate result would be used by using a combination of the two conventions but then such additional accuracy might be considered unnecessary. The whole procedure is intended as an aid to arriving at a rational ordering of alternatives. The ranking of alternatives will not normally be affected by which convention is chosen. The tables provided by Ref. 2 and Ref. 5 are based on the uniform flow convention and explained as an average of consecutive end-of-year factors.

## E. THE PROBLEM OF ESTIMATING COSTS

### 1. Initial Cost Estimates

The procedures involved in life cycle cost analysis do not single-handedly assure greater accuracy in investment decisions. The initial cost estimates, both for investment costs and recurring operating costs are the prime determinants of accurate analysis. The initial estimates must be as accurate as possible and certainly all inclusive. Cost elements omitted from the analysis invariably lead to greater distortions than errors in estimating those elements that are included.

Initial investment costs are usually based on a construction cost estimate plus various front-end costs on the project. The level of detail in the cost estimate varies with the stage of design development. Early in the project the estimating parameters may be overall dollars per square foot of building or an average cost per BOQ room. Later in the project more detailed parametric estimates will

be developed based on unit estimates for different elements of the building such as dollars per square foot of exterior walls, interior walls, roof surfaces, or dollars per light fixture. In the final construction estimates there will be a detailed breakdown for each category of labor and materials the contractor will use in constructing the facility. In most cases this will be the most accurate estimate of initial cost.

The initial estimates of operating costs will also be engineered estimates. For example, detailed procedures are used to estimate the energy use in a building. The owner's estimate of functional use costs for each of the years under consideration will also be included. Obviously it is difficult to project such estimates very far into the future. Even energy costs are highly variable depending on how the owner operates his business. Will an energy conservation program always be in effect? Will the amount of ventilation air required stay the same? Will manufacturing processes change demanding more electrical consumption? The analyst must have initial estimates for these cost elements. They cannot be accepted as 100% accurate in any case but any analysis must be based on the best information available.

2. Frequency of Changes

Some routine changes during the economic life of a building can be anticipated. The accuracy of these projections will seriously affect the life cycle cost analysis. A later example will illustrate the question of relocating partition walls. Will changes be made every three years or every five years? The analyst must make some kind of a judgement as he develops his study. Ideally there would be historical precedent to guide him. Realistically

little data has been collected on previous experience and analysts are on their own for the most part.

Some guidance has been published on the average life cycles of different items of mechanical equipment. Some analysts use the data on average useful life provided in the Energy Research and Development Administration (ERDA) manual entitled, Life Cycle Costing Emphasizing Energy Conservation [Ref. 6 ]. Some brief guidelines for different types of buildings are provided in Ref. 2. What is really needed though is not the overall building life but the expected useful lives of different elements of the building. It is generally recognized that if various elements of a building are replaced as they wear out the building can enjoy an overall useful life much beyond that originally planned. The Navy's experience with "temporary" wooden buildings constructed in WWII is sufficient evidence of this point. Some estimates of the life of building components can be obtained from manufacturers or materials suppliers. Some firms are developing their own estimates based on in-house experience. The Navy seems to have enough experience within the NAVFAC family but it requires much more development to bring it into a form which could be directly used by the analyst. Informed judgment is now the watchword for estimating the frequency of change of individual building elements.

### 3. <u>Cost of Replacements</u>

The estimates of costs of replacements can introduce additional errors into a life cycle cost analysis. Every engineer who has sat in on a bid opening for repair and renovation work is aware of the range of responses generated by the uncertainty associated with replacements. Most parametric estimating manuals are based on new construction.

Most estimating for repair work is done by modifying estimates for similar work in new construction. The possibilities for error are compounded in this situation.

### 4. Maintenance Policy and Costs

The amount of money to be spent on maintenance is largely a matter of policy and the amount of money available. These two items will have a significant effect on any life cycle cost analysis. If one firm intends to paint the exterior walls frequently to maintain a sharp appearance and another paints only as often as necessary to protect the structure from further deterioraton they will obtain very different results from the LCC analysis. Again this is a matter requiring judgment on the part of the analyst. Alternatives must be compared on an equal basis, so the same results-oriented maintenance policy must be applied to all alternatives and the policy anticipated must be reasonably accurate.

## F. EXAMPLES

Appendices A through C contain examples of life cycle cost calculations for potential cost savings relating to operations, maintenance, and repair or replacement. A review of these appendices will provide guidance on use of the techniques previously described in this chapter.

# IV. CURRENT FEDERAL EFFORTS IN LCC

## A. INTRODUCTION AND OVERVIEW OF CHAPTER

Most of the application of LCC in the federal government has been in connection with weapons systems development. This chapter examines recent experience with LCC in the military/industrial community, pointing out some of the problems with the mass of data and the variety of applications involved. Current efforts in the application of LCC techniques to building design are reviewed concluding with a summary of a computer model now being used by the Navy for evaluating design alternatives.

## B. MILITARY INDUSTRIAL LCC EXPERIENCE

### 1. Weapons Systems

Much of the pioneering work in the use of LCC models has occurred in weapons systems development. The mathematical models generated to study the long range cost implications of systems design decisions have been much more detailed and complex than the models now in use for building design.

a. LCC Models

Reference 7 presents a compilation of five automated LCC models for small arms and combat vehicles. This paper includes mathematical models, nomenclature lists, derivations of pertinent relationships, and detailed Fortran computer programs to use in LCCstudies. The study used multiple categories of cost and 110 elements or sets of data.

Other detailed studies concentrate entirely on the mathematical aspects of LCC modeling, examining the treatment of parameters, time phasing, and sensitivity analysis. An early Army study, Ref. 8, uses two types of sensitivity analysis. The first is changing the values of variables in the LCC equations. The second uses partial differential equations to derive sensitivity equations in terms of each of the variables. With many different organizations separately studying the application of LCC to weapons systems development, many inconsistencies arose. Much of the controversy over use of LCC naturally grew from the inconsistencies and much effort has been directed at developing guidelines for more uniform application of the techniques.

b. Contractual Implications

An important question in the minds of many weapons systems procurement managers has been the relationship of LCC programs to other procurement techniques such as design to cost. If a weapons contractor is obligated to deliver a weapons system for a specific cost, can he select alternatives which minimize initial cost at

the expense of higher operating costs? As the techniques of LCC have now been blended with "design to cost" programs it has become clear that production unit costs are only one part of the total life cycle costs. Setting constraints on this one part of the total costs does not negate the applicability of the entire concept. When LCC techniques are to be included in a procurement it is generally recommended that the LCC model to be used, the parametric definitions and source selection criteria should be included in the development contract and preferably in the Request For Proposals. Tradeoffs between design-to-cost and life cycle cost must be considered in the earliest stages of design [Ref. 9 ].

2. The Boeing Summary

The decade of the 60's saw many different models developed for use in defense systems projects. The programs multiplied so rapidly that soon serious questions were being asked in defense industry about how good the technique really was for solving practical problems. Some firms seriously questioned the validity of the process for application in an era of turbulent technological development. One firm which did a thorough study of the whole LCC process was the Boeing Company of Seattle. Boeing published a study in 1974 which examined the current state of the art in life cycle costing and system effectiveness. The study contains a bibliography of 160 documents referencing LCC and evaluated 14 computer programs which provide a data base for various LCC studies [Ref. 10 ].

a. Philosophy

The philosophy of the Boeing study was to seek

out a cost analysis technique that is simple, flexible, low cost, and easily applied in various degrees of detail by engineers throughout the early stages of design. Only functional elements significantly sensitive to cost should be analyzed in detail. Standard design factors should be applied elsewhere. Several methods of providing cost awareness or guidance were being considered.

b. Problems

In their study of LCC the group from Boeing interviewed many engineers and managers with direct experience in using LCC models for weapons systems development studies. Personnel interviewed were generally from the systems analysis groups of Boeing, RAND Corporation, Air Force, Navy, and the Army. The sources were not quoted directly but Boeing summarized what they felt was the consensus of the interviews. The consensus was that there were definite problems with the application of LCC techniques.

(1) Specific Applications

It was found that most LCC models were designed for specific rather than general application. The pre-existing models were not effectively applied to new programs nor were they readily available for general use. This could be a result of the diverse nature of weapons systems. The parameters of life cycle cost for a tank or a small arms weapons program would certainly be different than those considered for a shipboard missle system.

(2) Lack of Valid Data

The problem of collecting valid data was

one of the main reasons given for the LCC models not being applied. Much of the data available was found to be incomplete, or at least suspect. It was recognized that the data base required for most models would be immense. The cost of collecting such data and transforming it to the format of the model was prohibitive in many cases.

c. Future of LCC

Some analysts interviewed by the Boeing study group felt that the concept of LCC modeling had run its course. Most models were nice for analysts to play with but for real world use they were not economically practical and were in fact unreliable. The study group commented that this seemed to be an accurate summary of the state of the art. At that time in fact the Boeing Corporation had only one contract (B-1 Avionics System) that had any requirement to perform LCC predictions. That requirement itself was oriented at showing the customer what the support costs would be and not for performing tradeoffs for the most effective product in the design stage. The volume of work on LCC in recent years indicates that the concept of LCC modeling has not run its course, in spite of the opinion of some individual analysts.

### 3. GAO on LCC

a. Decisions

The Government Accounting Office (GAO) has ruled consistently that LCC is a valid procurement technique. That endorsement carries with it a series of decisions affecting procedures which must be observed when conducting

a procurement with LCC considerations. Provisions for award to the responsible bidder whose bid is the most advantageous to the United States, "price and other factors considered," is a familiar concept to contracting officers. LCC can be one of the factors considered in an award but only if bidders have been informed that LCC will be one of the factors used in the evaluation of bids. There must be a definite and concise showing with respect to lower maintenance and operations cost if that is to be used as a basis for award to other than the lowest bidder. The most crucial problem is to identify the LCC factors with sufficient clarity and definiteness to enable bidders to know precisely how their bids will be evaluated. The costs presented in any LCC procurement must be certain and non-speculative.

b. Comments to Agencies

GAO has suggested increasing use of LCC. It has also suggested a switch in organizational orientation from procurement to engineering organizations. GAO has asked for a more continuous effort at developing and implementing LCC techniques, more application to non-competitive procurements as well as competitive procurement, and more use of LCC at the subcontractor level [Ref. 11].

4. Construction Industry

a. Collection of Data Base

The construction industry is showing a great deal of interest in LCC techniques. The central problem of adequate data collection is still a subject of much concern.

Some leaders of the industry feel that collection and dissemination of a data base ought to be done by public bodies since the private sector cannot afford to do it adequately on an organized basis. Others feel that the manufacturers of construction materials and subcomponents should take the lead in developing life cycle cost experience on their products. A specialty area of LCC consulting has been developing recently to serve both public and private concerns as they develop more detailed applications of older disciplines of economic analysis [Ref. 12 ].

b. LCC and Performance Specifications

The interface of LCC with performance specifications is an important point to note. Performance specifications are based on a functional description of what a building product is supposed to do. The specification does not detail how a particular building element is to satisfy the problem, it just describes the problem to be satisfied. If not properly done a performance specification could be bid low on initial cost but end up costing the owner more in the long run. To be really effective, performance specifications must be committed to an evaluation procedure which includes extensive use of life cycle costing. Increasing attention to life cycle costing should inevitably improve the quality of building systems and materials [Ref. 13 ].

c. Materials Manufacturers

To date there appears to be no centralized effort on the part of materials manufacturers or the construction and design communities to develop a data base

to serve the industry. Some firms are collecting information on their own products, others rely heavily on what can be gleaned from federal research contracts and academic research. There has been some effort most recently on the part of the American Institute of Architects (AIA) to advance the use of LCC techniques. Their recently published "Life Cycle Costing, A Guide for Architects", explains the basic process very clearly and outlines a recommended format for analysis. The architects have done some collaboration with the General Services Administration in seeking a common format for the study of functional systems in buildings. These efforts in seeking a common format could lead to a sharing of cost experience data between the private and federal sectors.

## C. OTHER FEDERAL AGENCY EFFORTS

Much of the development in the use of LCC models in the late 1960's and early 1970's occurred in the Department of Defense, working on weapons systems and ship systems. The use of LCC models on facilities oriented design work has seen an increase in the mid-1970's in the larger federal agencies.

### 1. GSA LCC in Public Buildings

The General Services Administration has worked extensively on its UNIFORMAT cost estimating system. This system is based upon a standard hierarchical framework of cost categories, elements, and items. Concurrently the American Institute of Architects was working on its MASTERCOST system, attempting to develop a national building cost data bank. Fortunately the two organizations recognized

the similarity of their goals and their resulting systems and merged the two efforts. The resulting hierarchical cost system now goes by the GSA name of UNIFORMAT. The UNIFORMAT system was described in detail in GSA's first publication on LCC, "Life Cycle Costing in the Public Building Service, Volume I" [Ref. 14 ].

GSA's second volume under the same title is its "how to" manual concerning LCC. It includes a discussion of LCC concepts and analysis considerations and a complete description of how the process should be done for federal office buildings. Detailed forms and step by step instructions for their use are provided. The interaction between building components is addressed by way of a UNIFORMAT Cost Matrix. A designer can use the matrix as a helpful reminder of what building systems might be affected by changes in any other system. A similar matrix is provided for energy interaction with individual systems.

GSA's program for LCC is well developed from a planning standpoint. It is less comprehensive than other programs which address functional related costs in more detail. No extensive data collection has yet been initiated by GSA.

### 2. HEW Studies for Hospitals

The Department of Health, Education, and Welfare has now published a series of manuals entitled "Life Cycle Budgeting and Costing, As an Aid in Decision Making" as a part of a five year study sponsored by the Public Health Service and the Federal Energy Administration [Ref. 15 ]. The purpose of their study is to improve the cost-decision making process associated with health facilities by developing a costing model that acts in parallel with

planning and design decision models. A look at the titles of the manuals published to date will give the reader an appreciation for the comprehensive scope of their work.

Volume I Processes and Concepts, Dec., 1975

Volume II Energy Handbook, June, 1976

Volume III Data Base Requirements,
Formats, and Sources, May, 1976

Volume IV Life Cycle Costing Procedures, June, 1976

Volume V Data Management Plan, Jan., 1977

The Data Management Plan picks up on the UNIFORMAT system being promoted by GSA and AIA and then carries it one step further. Because of the high cost impact of functional operation-related resources on the health care industry the data management plan prepared by HEW provides for collecting functional cost data. The data base required becomes more comprehensive and the computer programs for analysis of the data becomes more complex. The next phase of the HEW study will be to develop the necessary life cycle costing models and programs and test them with data collected in accordance with their Data Management Plan.

3. ERDA LCC Applications

The Energy Research and Development Administration, ERDA, published a manual entitled, "Life Cycle Costing Emphasizing Energy Conservation" in September, 1976 with revisions in May , 1977 [Ref. 6 ]. The handbook discusses the process of life cycle costing as a method for dealing with energy conservation design alternatives aimed primarily at retrofitting existing facilities. By using the analysis concepts set forth in the manual budget requests for energy conservation programs will be standardized. This will allow a comparable ranking of budget contenders. The procedures described provide for a series of levels of analysis

depending on complexity of the project. A nomogram analysis technique is presented which allows screening out of many projects before expensive and detailed analysis is necessary. The focus on energy is evident in the introduction of the economic measurement concept of BTU/investment dollar.

## D. WESTDIV'S LCC MODEL

An efficient LCC model is in current use by the Western Division, Naval Facilities Engineering Command, San Bruno, California. The model has been titled "An Economic Building Performance Model (EBPM) after a thesis of the same title by Mr. Stephen Kirk, AIA. [Ref. 16 ]. (Mr. Kirk introduced the model at WESTDIV and worked on development of a data base to support it until his departure in July 1977 to accept employment with the civilian firm of Smith, Hinchman, and Grylls Associates, Inc. of Washington, D. C.)

### 1. The Model

EBPM focuses on the energy costs for lighting, heating, cooling, and equipment, and on costs for maintenance, replacements, and fire protection. The model is based on parameters provided by the designer. The parameters include a description of various elements of the building, the climatic factors, orientation of the building, utility operating charcteristics and applicable costs, and economic assumptions. The model permits substitution of different parameters as the designer trys alternative layouts or choices of material. Printouts are provided which give the total life cycle cost of each alternative with sufficient backup data for interpreting the results.

### 2. The Data Base

Work has begun on development of a cost data base for use with the model. The cost data base is in a building systems format using a computerized cost estimating system being developed by the Atlantic Division, Naval Facilities Engineering Command. Historical information on maintenance costs is being developed from the Navy's maintenance control experience. The data base is not fully developed but many elements are already included. The data base is being expanded as each new project is studied. Experience with the model and the data base has been very sucessful so far.

### 3. Problems and Further Developments

Development of the EEPM is continuing. The model itself is being improved as the data base development continues. Further developments are desirable, especially the development of some automatic procedure for formatting the Navy's vast cost experience with maintenance and replacement programs in a way which would allow direct access.

# V. SUMMARY AND CONCLUSIONS

## A. LCC IN PERSPECTIVE

The development of LCC models in the military/industrial establishment seems to have run in a cycle of increasing complexity. As the models get more and more complex they become more esoteric, less useful on a broad basis, and extremely demanding in their requirements for data. The frustration of trying to obtain a perfect model of a complex system leads to criticism of the LCC technique and waning enthusiasm for attempts at prediction. At some point the decline is stopped by a recognition that the life cycle approach is still better than the narrow consideration of only initial costs. The technique can be applied, but it must be applied judiciously. The technique may be cumbersome in the most extremely complex applications but it can be very useful in less complex and more predictable areas. Facilities design is one area where the models may find worthwhile application.

## B. TOWARDS A COMMON FORMAT

One of the most prevalent problems noted in the military/industrial experience with LCC has been the lack of a common format. The same problem occurs in the application of LCC to building design. Lacking any broadly accepted format, each designer adopts the basic concepts to his own

use and presents his analysis in whatever form he considers will provide the clearest explanation of his analysis. The result is a wide variety of nomenclature and form of presentation.

The recent efforts of GSA and AIA should help lead the construction industry towards a common format for LCC analysis. The development of the UNIFORMAT system is a first step for the industry. Other steps needed are agreement on terminology, agreement on simplified form for presenting the analysis, agreement on the treatment of inflation, and agreement on the use of Equivalemt Uniform Annual Cost or strictly present value analysis in tradeoff decisions. This is not to say that these two organizations should dictate how LCC will be used in the construction industry. What they have done is to set a tone of cooperation. Other industry leaders should join in and work toward a common format which will strengthen the usefulness of the LCC tool.

## C. BUILDING A DATA BASE

Good data is essential to a good LCC analysis. Unfortunately, good data is almost non-existent, at least in the form in which it is needed. Maintenance and operations data is collected by many organizations. Some utility cost data is excellent. It will provide a sound basis for estimating fuel consumption for expected climatic conditions. Some maintenance data is good, particularly on housekeeping expenses such as floor care and relamping. For the most part, however, maintenance data on building systems is not extensive and not available outside the particular organization. Each owner maintains some kind of records useful within his own plant and in the form he finds

convenient. Collection of that data in a systems format with direct application to LCC studies is not being done.

This lack of data should not bar effective use of LCC, however. The data that is available should be transformed into a useful form. New data can be added as each new study is done, gradually building a data base with broader application. Broader application again depends on a common format. Within DOD, there exists a great deal of cost experience relating to buildings. If a way can be found to directly collect that experience in a systems format, an adequate data base would soon be a reality. It is recommended that the Naval Facilities Engineering Command pursue collection of its construction and maintenance cost data in a systems format which can be directly accessed for LCC studies.

## D. USEFULNESS OF THE TOOL

When struggling with the complexities of diverse formats and elusive data the designer must not lose sight of the purpose of LCC in building design. The LCC analysis is a tool, a technique to assist in making design decisions. It does not have to be absolutely perfect to be useful in ordering alternatives. The application of the technique can be exceedingly complex or fairly simple depending on the level of decision being considered. In applying LCC models to facilities design a lesson can be learned from the broader military/industrial experience. If kept simple, there is a good opportunity to keep LCC useful.

# APPENDIX A

# LCC IN HEATING ANALYSIS

## A. BACKGROUND

Calculating the heat load for a building involves determining the amount of heat lost to the exterior through each of the buildings components and then adding the components to determine total heat loss. The usual elements of the heat load calculation are losses through walls and ceilings, infiltration losses around windows, and additional heat needed to raise the temperature of ventilation air brought inside the building. A detailed heat load calculation requires the integration of heat losses from all sources over the specific time under consideration. Such a detailed calculation is provided by several computer programs in general commercial use.

For purposes of illustrating the life cycle cost calculations, it is not necessary to know all elements of the heat load. Savings on any one element of the total calculation will be reflected in the savings on the overall total. By knowing the thermal properties of one building element, such as walls, that component's contribution to total energy use can be calculated according to the following formula.

$$\text{Heat loss } Q = U \bullet A \bullet dT \qquad \text{[Ref. 16 ]}$$

where,

Q = heat loss in BTU/Hr

U = U-factor (thermal transmittance factor)

A = Area of exterior building surface

dT = Temperature difference between winter inside and outside

The annual heating cost is then calculated according to the formula:

$$C_h = \frac{24\ C\ Q\ D_h}{1{,}000{,}000dT} \qquad \text{[Ref. 16 ]}$$

where,

$C_h$ = Annual cost of heat

C = Cost ($) per million BTU output

$D_h$ = Number of heating degree days per year

dT = Temperature difference

Combining these two equations, we find

$$C_h = \frac{24\ C(UAdT)\ D_h}{1{,}000{,}000dT}$$

by cancelling dT, the equation can be rewritten as:

$$C_h = \frac{U\ (24CAD_h)}{1{,}000{,}000}$$

From this equation it can be seen that the annual cost of heating the building varies directly with the thermal resistance or U-factor for the building component. The cost savings to be gained from additional thermal insulation can then be compared on a life cycle basis with the cost of providing additional insulation.

## E. WALL INSULATION EXAMPLE

### 1. Introduction

This will be a hypothetical example to illustrate the application of ICC techniques to the problem of insulation for a home. The simplest situations will be compared. The base alternative will be a hollow light weight block wall, 8 inches thick. The alternative considered will be addition of 2 inches of polystyrene board insulation to the room side of the wall. The following assumptions are made [Ref. 17 ].

### 2. Assumptions

Prices and insulation values are based on Masonry Wall Cost, 1977-78, National Association of Brick Distributors, Northern Ohio Chapter. The prices given will be in terms of per square foot of wall area. Considerations for openings and maintenance are excluded as being essentially the same for either alternative.

The block wall is $1.75/SF but since this is the same for both alternatives the only cost considered will be the addiitonal $0.45/SF to add the 2 inches of polystyrene board insulation.

The location of the building is in Cleveland, Ohio, which has winter climatic conditions as follows: 6,350 degree days; 7 Deg. winter outdoor design temperature; 37.2 Deg. average winter temperature. The building will be

assumed tc require a 72 Deg. indoor temperature.

The U-factor for the block wall is .35 and the addition of insulation changes the U-factor tc .10.

The building is heated with natural gas at a ccst of \$1.93/MMBTU adjusted for a coefficient of efficiency of .6 giving a ccst of heat delivered of \$3.23/MMBTU. This equates to a cost of .32 per therm (100,000BTU) which is a relatively inexpensive cost of fuel. The gas price will be assumed tc inflate at a differential inflation rate of 7% in excess of the general economy's inflation rate.

3. Hollow light weight block wall alternative

$$Q = U \bullet A \bullet dT$$

$$= (.35)(1)(72-37)$$

$$= 12.25 \text{ BTU/HR}$$

$$C_h = \frac{24 \bullet C \bullet Q \bullet D_h}{1{,}000{,}000 \bullet dT}$$

$$= \frac{(24)(3.23)(12.25)(6{,}350)}{(1{,}000{,}000)(35)}$$

$$= \$0.172/\text{SF/YR}$$

4. Basic wall with 2 in. insulation added alternative

$$Q = U \bullet A \bullet dT$$

$$= (.10)(1)(35) = 3.5 \text{ BTU/HR}$$

$$C_h = \frac{24 \bullet C \bullet Q \bullet D_h}{1{,}000{,}000 \bullet dT}$$

$$= \frac{(24)(3.23)(3.5)(6{,}350)}{(1{,}000{,}000)(35)}$$

$$= \$0.049/SF/YR$$

5. <u>Cost savings due to insulation</u>

$$\begin{array}{r} .172 \\ -.049 \\ \hline \end{array}$$

\$ .123/SF/YR for the first year

6. <u>Cash flow diagram, wall insulation</u>

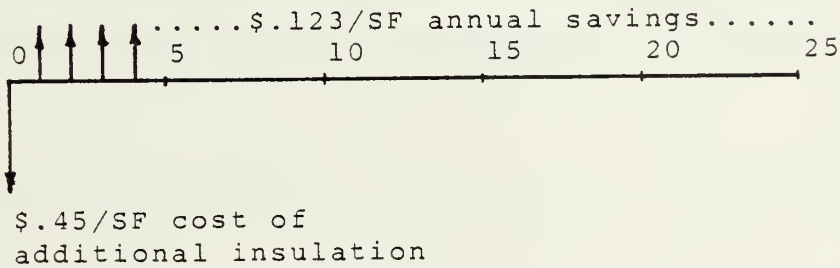



Figure A-1

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial cost of added insulation | .45 | | 1.00 | .45 |
| 1-25 | cost benefit of fuel savings | | (.123) | 18.049 | (2.22) |
| | TOTAL NPV BENEFIT | | | | $1.77/SF |

Table A-i

### 7. Discussion of results

It was obvious from the start that the addition of insulation to a block building in Cleveland would provide benefits in excess of the cost incurred. The effect of inflation is considerable. Using no differential inflation the total NPV benefit over a 25 year life would have been $.72/SF. When inflation is considered the benefit jumps to $1.72/SF. It is interesting to note in this hypothetical example that the additional cost of insulation could have been as much as the original cost of the wall ($1.75/SF) and it still would have produced net benefits of $.47/SF over the 25 years that gas prices are assumed to be rising.

## C. ROOF INSULATION EXAMPLE

### 1. Introduction

Life cycle costing can be used to make comparisons of alternative amounts and placement of roof insulation. For this example a comparision will be drawn between a wood construction flat roof and ceiling with roof deck insulation and the same roof with no roof deck insulation but with R/19 insulation in lieu of the air space between the ceiling and the plywood deck. Only incremental costs of the two alternatives will be considered.

### 2. Assumptions

Prices are based on National Construction Estimator, 1977 Edition edited by Gary Moselle, Craftsman Book Company,

Solona Beach, Ca. Prices given will be in terms of square feet of ceiling and roof area.

The basic alternative will be a flat wood roof with built-up roofing over a 1/2" thick preformed insulation board with a thermal resistance R of 1.39. The U-factor for this alternative is 0.17.

The alternative construction will delete the roof deck insulation and add 6" of fiberglass insulation (R-19) into the air space between the ceiling joists. The U-factor for this assembly is 0.04.

The cost of the 1/2" roof deck insulation is $ .236/SF and the cost of the R-19 insulation is $ .328/SF or a net additional cost of $ .092/SF.

The winter design parameters are the same as in the previous example for wall insulation.

3. <u>Roof deck insulation alternative</u>

$$Q = U \bullet A \bullet dT$$

$$= (.17)(1)(35)$$

$$= 5.95$$

$$C_h = \frac{24CQD_h}{1{,}000{,}000\ dT}$$

$$= \frac{(24)(3.23)(5.95)(6{,}350)}{(1{,}000{,}000)(35)}$$

$$C_h = \$.084/SF/YR$$

4. R/19 insulation alternative

$$Q = (.04)(1)(35) = 1.40$$

$$C_h = \frac{(24)(3.23)(1.40)(6{,}350)}{(1{,}000{,}000)(35)}$$

$$= \$.020/SF/YR$$

5. Cost savings to first alternative

$.084/SF/YR
-.020
$.064/SF/YR first year savings

6. Cash flow diagram, roof insulation

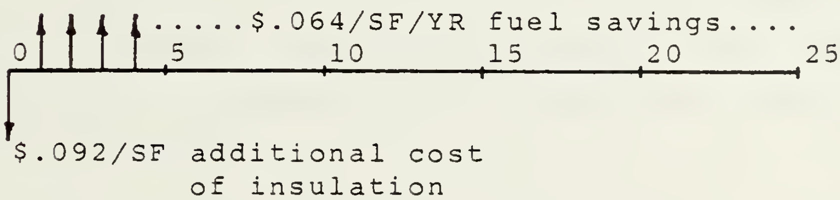



Figure A-2

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial cost of added insulation | .092 | | 1.00 | .092 |
| 1-25 | savings on fuel | | (.064) | 18.049 | (1.155) |
| | | TOTAL NPV BENEFIT | | | $1.06/SF |

Table A-ii

7. Discussion of results

The example again shows the long run benefit of added insulation in the northern areas of the United States. It also demonstrates that it is not necessary to include all of the costs of the roof construction in the analysis. Only those costs which vary for each alternative must be included. However, this same line of reasoning cannot be applied to the insulation. U-factors cannot be added or subtracted directly. The change in the U-factor from the addition of a certain quantity of insulation is dependent on what the original combined U-factor was for that particular construction assembly.

Once the different U-factors have been determined and the cost differential required to produce the change in U-factor, the climatic and energy cost parameters can be combined with the LCC techniques to determine the NPV of the benefit of additional insulation.

## D. SOLAR ENERGY EXAMPLE

### 1. Introduction

The prospect of free energy from the sun to supplement the increasingly expensive use of fossil fuels is becoming more attractive each year. The investment in solar heating equipment cannot be based merely on implications of initial cost comparisons. Any energy related investment must look to the future and use the Life Cycle Cost techniques as a means of examining the investment alternatives. A solar energy economic analysis is demonstrated using the vehicle of a simple example.

The solar energy question is basically an examination of costs incurred and benefits received. The costs incurred are for equipment; the collectors, piping, pumps, control systems; and for operation and maintenance of the system. The benefit derived is energy - energy in the form of heat delivered. This energy is measured in the familiar units BTU's. The energy delivered is measured in the same units as the energy delivered by the normal furnace using natural gas or fuel oil. The benefit can be evaluated in terms of dollars that would be paid for the same amount of energy from fossil fuel. For example, if the delivered cost of energy from natural gas is $3.23 per million BTU, then one million BTU's of energy delivered by the solar heating system can be valued at the same $3.23.

Most of the calculations involved with design of solar heating systems are directed at arriving at the amount of energy collected and ultimately delivered to the

building. That delivered energy is called the solar contribution. Once the economic analyst has been given the solar contribution and the investment and operating costs necessary to produce that contribution, he can proceed to apply the LCC technique.

2. Flagstaff Observatory solar example

This example is adapted from an Energy Conservation Investment Project prepared by Western Division, Naval Facilities Engineering Command for the Naval Observatory, Flagstaff, Arizona. The documentation on which the example is based is the Project Engineering Documentation (PED) dated 1 June 1976 [Ref. 18 ]. The PED does not contain the complete economic analysis so certain assumptions will be made for purposes of illustration.

The project calls for the installation of a new solar heating system on each of three buildings to supplement the existing heatnig system. Building No. 1 is presently heated by a propane fired forced air heating system. Buildings No. 4 and 6 are presently heated by electric resistance heaters.

3. Assumptions

The solar contribution for each building has been calculated based on the type of system, the climatic conditions in Flagstaff, and the optimum balancing of solar collector area and operating economics. For purposes of this example the solar contribution will be accepted as set forth in the PED, namely:

Bldg. No. 1 $202.4 \times 10^6$ BTU/YR

Bldg. No. 4 $324 \times 10^6$ BTU/YR

Bldg. No. 6 $249.6 \times 10^6$ BTU/YR

The unit cost of energy at the beginning of the project life will be:

electricity $.045/KWH
propane $56.25/GAL

The differential inflation rate for electricity will be 3% for electricity and for propane will be 7%/yr.

The annual maintenance cost for the supplementary solar heating system will average 2% of the initial investment cost.

4. Energy savings

The type and quantity of energy saved is calculated as follows:

Building No. 1 Propane savings

$$\frac{202.4 \times 10^6 \text{ BTU/YR}}{(.065)(9.55 \times 10^4 \text{ BTU/GAL})} = 3.26 \times 10^3 \text{ GAL/YR}$$

Building No. 4 Electricity savings

$$\frac{324 \times 10^6 \text{ BTU/YR}}{3.414 \times 10^3 \text{ BTU/KWH}} = 94.9 \times 10^3 \text{ KWH/YR}$$

Building No. 6 Electricity savings

$$\frac{249.6\times10^{6}\ \text{BTU/YR}}{3.414\times10^{3}\ \text{BTU/KWH}} = 73.1\times10^{3}\ \text{KWH/YR}$$

5. <u>Annual cash flows</u>

The unit costs of energy and the annual consumption are converted to annual cash flows as follows:

Building No. 1 (propane)

$3.26\times10^{3}$ GAL/YR x \$56.25/100GAL = \$1833.75

Building No. 4 (electricity)

$94.9\times10^{3}$ KWH/YR x \$.045/KWH = \$4270.50

Building No. 6 (electricity)

$73.1\times10^{3}$ KWH/YR x \$.045/KWH = \$3289.50

The investment cost and annual maintenance cost for each of the independent solar heating systems will be:

| | | | |
|---|---|---|---|
| Building | No. 1 | $19,698 | 400 |
| | No. 4 | $30,832 | 600 |
| | No. 6 | $25,520 | 500 |
| | Total | $76,050 | |

6. Cash flow diagram, Building No. 1

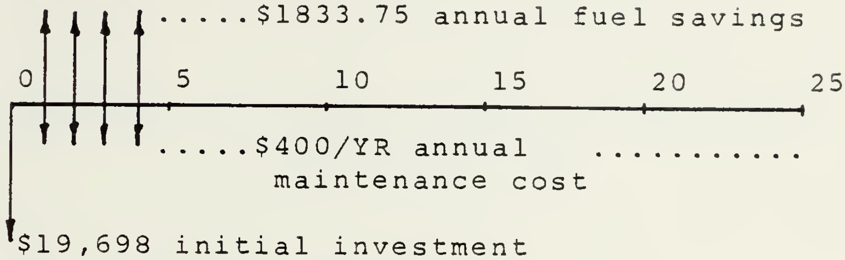



Figure A-3

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial investment | 19,698 | | 1.000 | 19,698 |
| 1-25 | annual maintenance | | 400 | 9.524 | 3,810 |
| 1-25 | annual fuel savings | | (1833.75) | 18.049 | (33,097) |
| | | TOTAL NPV BENEFIT | | | ($9,590) |

Table A-iii

7. <u>Cash flow diagram, Building No. 4</u>

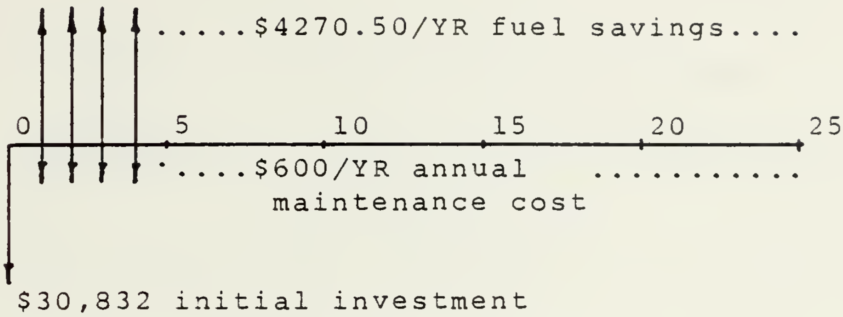



Figure A-4

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial investment | 30,832 | | 1.000 | 30,832 |
| 1-25 | annual | | 600 | 9.524 | 5,714 |
| 1-25 | annual fuel savings | | (4270.50) | 12.270 | (52,399) |
| | TOTAL NPV BENEFIT | | | | ($15,853) |

Table A-iv

8. <u>Cash flow diagram, Building No. 6</u>

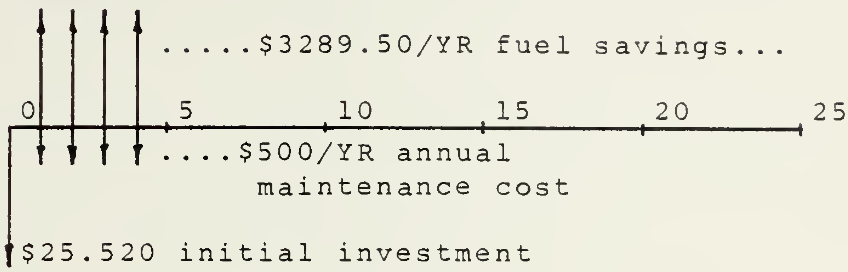



Figure A-5

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | initial investment | $25,520 | | 1.000 | $25,520 |
| 1-25 | annual maintenance | | 500 | 9.524 | 4,762 |
| 1-25 | annual fuel savings | | (3289.50) | 12.270 | (40,362) |
| | | TOTAL NPV BENEFIT | | | ($10,080) |

Table A-v

9. <u>Discussion of results</u>

The LCC analysis shows that for each building the benefits to accrue over the theoretical 25 year life would exceed the costs incurred to obtain those benefits. In each of these projects differential inflation plays an important role. It is interesting to note for example the effect on

the building No. 1 analysis if it were assumed that the cost of propane would inflate no faster than prices in the general economy. In that case the discount factor would be 9.524 for the annual fuel savings and the total net present value of the project would be a cost of $6043 instead of the projected benefit of $9,950.

# APPENDIX B

# LCC IN MAINTENANCE ANALYSIS

## A. INTERIOR FLOOR SURFACES

### 1. Introduction

The problem of selection of interior floor surfaces should by now be a classic illustration of the importance of life cycle cost analysis. In a heavy use area the cost to maintain vinyl tile can be over 25 times its initial cost when considered over an 18 year life. Under the same conditions carpet costs less to maintain even though it has a higher initial cost. A valid comparison of the two types of flooring can only be made with a life cycle cost analysis. This example will also demonstrate the effect of maintenance policy on life cycle costs.

This example is based on a preliminary design for the New Generation Military Hospital at Travis AFB, Ca. [Ref. 19 ]. The architect studied three different grades of carpet, vinyl asbestos tile, sheet vinyl, and terrazzo. It is not necessary to compare all six types of flooring to illustrate the process so three have been selected; medium grade carpet, vinyl asbestos tile, and terrazzo. It is recognized that there is a great difference in the physiological effects of the "hard" and "soft" surfaces

under consideration. The additional comfort and desirable properties of carpet have not been quantified in the comparison.

2. Assumptions

The medium grade carpet costs $15.00 per square yard plus $2.00 per square yard to install for an initial cost of $1.89/SF. It last 8 years and costs $2.00/SF to replace. Included in its maintence cost is:

| | |
|---|---|
| Vacuum daily | $.20/SF/YR |
| Clean monthly | .45 |
| Minor repairs | .08 |
| Total | $.73/SF/YR |

The vinyl asbestos tile costs $.74/SF to install and should be replaced every 18 years at a cost of $.82/SF. Included in maintenance cost is:

| | |
|---|---|
| Mop daily | $.41/SF/YR |
| Wax weekly | .58 |
| Strip quarterly | .03 |
| Minor repairs | .03 |
| Total | $1.05 |

The epoxy terrazzo costs $3.52/SF. It never needs replacement but it does need sealing at 4 year intervals at a cost of $.18/SF. The cost to maintain is:

| | |
|---|---|
| Mop daily | $.41/SF/YR |
| Minor repairs | .09 |
| Total | $.50 |

To account for the unequal lives of the alternatives the present worth of their residual value at the end of 25 years will be added to their net present value. For example, the carpet will have 7 years useful life remaining

after having been replaced for the third time in year 24.

3. Cash flow diagram, medium grade carpet alternative

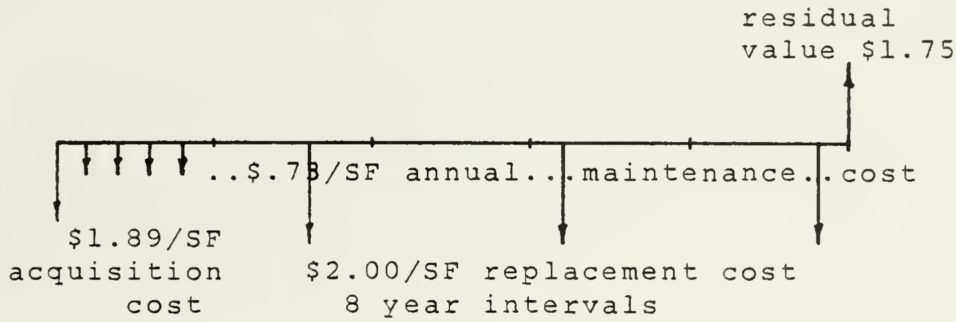



Figure B-1

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | acquisition cost | $1.89 | | 1.000 | 1.89 |
| 1-25 | maintenance cost | | .73 | ..524 | 6.953 |
| 8 | replacement | 2.00 | | .489 | .978 |
| 16 | costs | 2.00 | | .228 | .456 |
| 24 | " | 2.00 | | .107 | .214 |
| 25 | residual value | (1.75) | | .097 | (.170) |
| | | TOTAL NPV COST | | | $10.32/SF |

Table B-i

4. Cash flow diagram, vinyl asbestos tile alternative

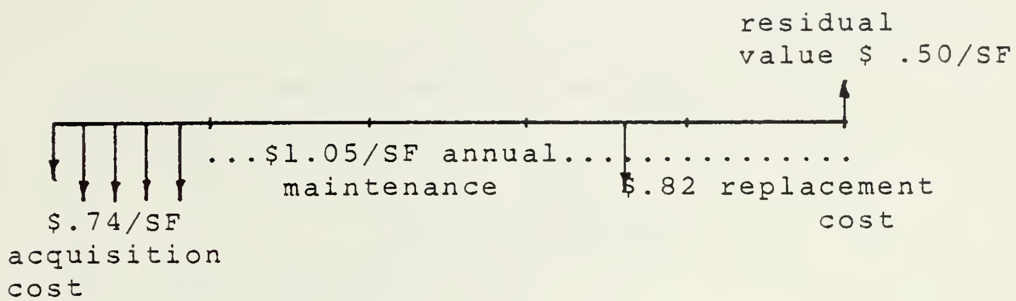



Figure B-2

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | acquisition cost | $.74/SF | | 1.00 | .74 |
| 1-25 | maintenance cost | | 1.05 | 9.524 | 10.00 |
| 18 | replacement cost | .82 | | .189 | .155 |
| 25 | residual value | (.50) | | .097 | (.049) |
| | | TOTAL NPV COST | | | $10.85 |

Table B-ii

5. Cash flow diagram, epoxy terrazzo floor alternative

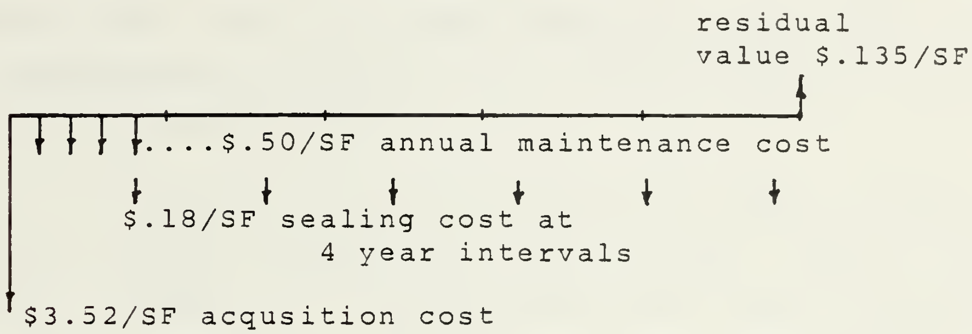



Figure B-3

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | acquisition cost | $3.52 | | 1.000 | 3.52 |
| 1-25 | maintenance cost | | .50 | 9.524 | 4.762 |
| 4 | sealing | .18 | | .717 | .129 |
| 8 | cost | .18 | | .489 | .088 |
| 12 | " | .18 | | .334 | .060 |
| 16 | " | .18 | | .228 | .041 |
| 20 | " | .18 | | .156 | .028 |
| 24 | " | .18 | | .107 | .019 |
| 25 | residual value | (.135) | | .097 | (.013) |
| | | TOTAL NPV COST | | | $8.63/SF |

Table B-iii

## 6. Discussion of results

The cash flow diagrams show the difference in the three alternatives. Note that the residual value of the periodic replacement or sealing cost has been included as a contra-cost or a benefit item.

This analysis shows that in spite of higher initial cost and more frequent replacement, the carpet, under the circumstances assumed, is competitive with vinyl asbestos tile. The epoxy terrazzo is shown to be even less costly in the long run. The lower maintenance cost as a result of no waxing, and the fact that it lasts the entire life of the building combine to produce a cost 18% below the average of the other two alternatives.

It is important at this point to consider the effect of maintenance policy on this analysis. These studies have assumed a heavily traffiked area and a maintenance standard requiring daily floor care. If a combination of less traffic and less stringent maintenance would reduce annual maintence costs to 1/3 of base levels, the tile would cost only 74% of the cost of carpeting. A higher grade carpet which required replacement less often would result in a lower life cycle cost. If the carpet were of a color and texture that could be vacuumed on alternate days while the tile still needed daily attention, the results of the analysis would change again. The significant impact of maintenance costs on the life cycle cost of interior flooring makes it of crucial importance to have accurate estimates of these costs. Inaccurate estimates, or a misunderstood maintenance policy, will significantly distort the analysis and lead to faulty design decisions.

## E. CORRIDOR DOOR FINISHES

### 1. Introduction

Corridor doors in a hospital receive very heavy use. Heavy use requires a good door to start with and a good maintenance program. Three types of doors are commonly used; solid core wood doors, hollow metal doors, and plastic clad doors. These three types offer significant tradeoffs between initial costs and life cycle costs. This analysis will again point out the effect of maintenance assumptions on the concept of life cycle cost analysis [Ref. 19 ].

### 2. Assumptions

Solid core wooden doors require kickplates and pushplates .

Normal painting frequency is 5 years for both hollow metal and solid core wood doors. Plastic clad doors require no painting. Average door size is 4' x 7'.

All costs are expressed in dollars per door.

Normal door hardware and door frames are ignored because costs are equal for all three types.

The life of the building will be assumed to be 25 years as in previous examples and the DOD discount factors will be used.

3. Corridor door cost data

Solid core wood doors

Installation cost $254

(including $86 for protective hardware)

Annual maintenance

| | |
|---|---|
| Custodial | $2.01/door |
| Repairs | $3.98/door |
| Total | $5.99 |

Painting every 4 years $20.50

Hollow metal doors

Installation cost $276

Annual maintenance

| | |
|---|---|
| Custodial | $1.89 |
| Repairs | $2.52 |
| Total | $4.41 |

Painting every 4years $20.50

Plastic clad doors

Installation cost $323

Annual maintenance

| | |
|---|---|
| Custodial | $1.44 |
| Repairs | $4.18 |
| Total | $5.62 |

Painting not necessary for plastic clad doors.

The cash flow diagrams show the relevant costs for the three alternatives. Note that the pericdic painting adds the same life cycle cost to the hollow metal and solid core doors ($32) but not to the plastic clad doors.

4. Cash flow diagram, plastic clad doors alternative

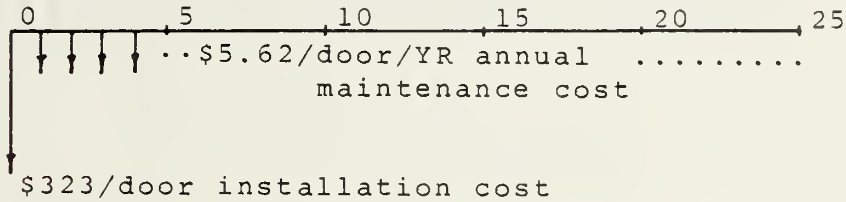



Figure B-4

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | installation | $323 | | 1.00 | $323.00 |
| 1-25 | maintenance | | 5.62 | 9.524 | 53.52 |
| | | TOTAL NPV COST | | | $376.52 |

Table B-iv

5. Cash flow diagram, hollow metal doors alternative

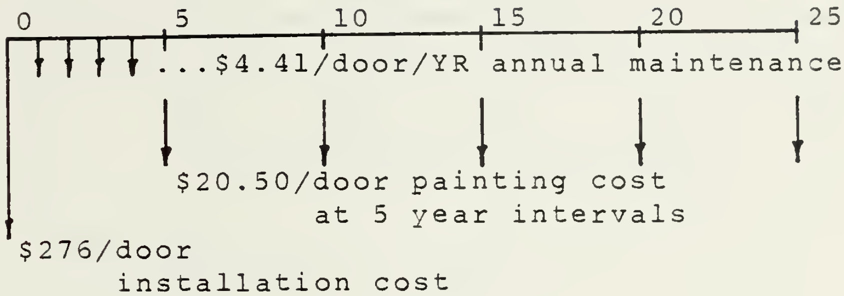



Figure B-5

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | installation | $276 | | 1.00 | $276.00 |
| 1-25 | maintenance | | 4.41 | 9.524 | 42.00 |
| 5 | painting | 20.50 | | .652 | 13.37 |
| 10 | painting | 20.50 | | .405 | 8.30 |
| 15 | painting | 20.50 | | .251 | 5.15 |
| 20 | painting | 20.50 | | .156 | 3.20 |
| 25 | painting | 20.50 | | .097 | 1.99 |
| | | TOTAL NPV COST | | | $350.00 |

Table B-v

6. <u>Cash flow diagram, solid core wood doors alternative</u>

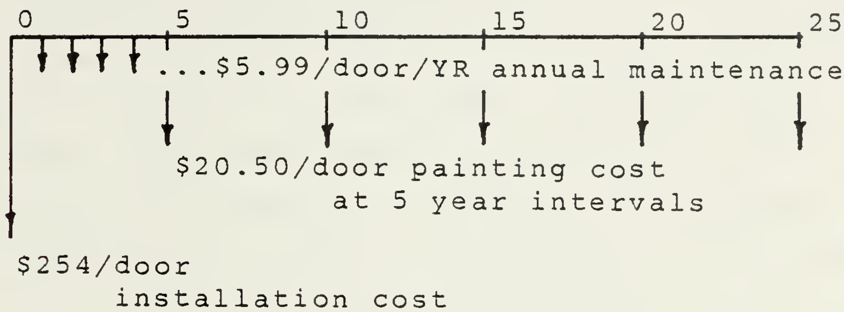



Figure B-6

| PROJ. YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | installation | $254 | | 1.00 | $254.00 |
| 1-25 | maintenance | | 5.99 | 9.524 | 57.05 |
| 5 | painting | 20.50 | | .652 | 13.37 |
| 10 | painting | 20.50 | | .405 | 8.30 |
| 15 | painting | 20.50 | | .251 | 5.15 |
| 20 | painting | 20.50 | | .156 | 3.20 |
| 25 | painting | 20.50 | | .097 | 1.99 |
| | | TOTAL NPV COST | | | $343.05 |

Table B-vi

7. <u>Discussion of results</u>

The plastic clad doors are highly regarded by many because they never need to be painted. In this analysis, however, the present value of the future painting costs for the other two types of doors does not make up for the fact that the plastic clad doors cost $47-$69 more originally and

cost $5.62/door/year to maintain. Most of that maintenance cost is due to the high cost to repair one of these doors when something happens to damage it.

Maintenance policy can have an effect on this analysis. If the painting schedule must be increased to once every three years, the LCC of hollow metal doors becomes $376.38, pulling up even with plastic clad doors. The solid core wood door rises only to $369.43 and remains the lowest cost alternative. If the plastic clad door could be repaired for the same price as the hollow metal door, its LCC would drop to $360 and it would become the lowest cost alternative. The cost of kickplates and pushplates adds $86 to the initial cost of the solid core door. In lighter use areas such as for closet doors the solid core door without protective hardware would be the obvious choice. Any reduction in the cost of protective hardware for the corridor doors would further enhance the competitive standing of solid core doors.

In this analysis the choice of discount rates has an effect on the outcome. In the original study the architect used an inflation rate of 6% for outyear costs and a discount rate of 9%. The base case results were then $434 for solid core, $427 for hollow metal, and $425 for plastic clad. The effective 3% discounting gives greater weight to the future painting costs than it is given in the DOD economic analysis.

## APPENDIX C

## LCC IN REPLACEMENT ANALYSIS

### A. WALL PARTITIONS

#### 1. Introduction

Wall partitions can be a significant part of the building's cost. The initially inexpensive gypsum wallboard partition has become an industry standard. It offers excellent fire resistant characteristics and is relatively easy to maintain when it incorporates a vinyl wall covering. In a situation where frequent partition changes are necessary, the standard gypsum wallboard partition meets good competition from the modular relocatable partitions, generally made of metal or some composition material which offers low maintenance and ease of relocation. This example examines these two alternative wall partitions for a hospital application, where future relocation or replacement is known to be probable [Ref. 19 ].

#### 2. Assumptions

The study covers a typical bay of a hospital project. The bay area is 4300 SF and contains 700 linear feet of wall partitions. Square foot costs are based on the

total area of the bay (4300SF) rather than on partition wall area.

A typical partition module is 40inches wide and 9 feet high. Effect of door spaces is equal in each case and is excluded from study.

The relocatable partitions are Hauserman double wall. The gypsum wallboard partitions are standard, using average prices.

Heavy duty surface protection is necessary to the wainscot level. 24 OZ vinyl is used on the lower third of the wall and 12 OZ vinyl above. The relocatable partition has a uniform baked-on enamel finish.

Each type of wall lasts the life of the building, including the vinyl wall covering.

Relocatable partitions are erected over the carpeting without damage to carpet. Gypsum wallboard partitions do not have carpet under them and change costs must include patching the carpet.

Annual maintenance costs include minor repairs and patching with custodial costs. Relocatable walls are to be scraped, primed, and finished every five years.

20% of the panels will be moved every five years.

25% of the panels will have service changes in them every five years. Changes include adding/removing electrical outlets, adding or removing glass, and adding or removing wall hung sinks.

100% of all moves and changes for gypsum wallboard

partitions will require face panel replacement. 15% of all moves and changes for relocatable partitions will require face panel replacement.

This commercial example uses 9% discount rate and 6% inflation.

There will be a time difference for erecting different kinds of partitions. This is accounted for by labor costs in the estimates . No allowance is made for the possible economic benefit to hospital operations when time is of the essence in alteration projects.

3. Wall partition cost data

| | Relocatable partitions | | | Vinyl covered gypboard | | |
|---|---|---|---|---|---|---|
| Operation | Freq. | Cost/LF | Cost/SF | Freq. | Cost/LF | Cost/SF |
| Installation | once | $45/LF | 7.32 | once | 38.79 | 6.31 |
| Maintenance | | | | | | |
| Custodial | annual | .78 | .12 | annual | .98 | .16 |
| Minor repairs | annual | .27 | .05 | annual | .58 | .08 |
| Repainting | 5 years | 5.28 | .86 | not necessary | | |

4. <u>Change cost data</u>

| | Relocatable partitions | | | Vinyl covered gypboard | | |
|---|---|---|---|---|---|---|
| Operation | Freq. | Cost/LF | Cost/SF | Freq. | Cost/LF | Cost/SF |
| Changes | 5 years | | | 5 years | | |
| Take down 20% of all partitions | | 2.53 | .28 | | 7.60 | .24 |
| Reinstall 20% | | 8.75 | .28 | | 26.00 | 1.25 |
| Service changes in 25% of all partitions | | 20.75/ panel | .25 | | 41.00/ panel | .51 |
| Ductwork and ceiling light changes | | | .25 | | | .25 |
| Total for changes | | | .87/SF | | | 2.25/SF |

5. <u>Cash flow diagram, relocatable partitions alternative</u>

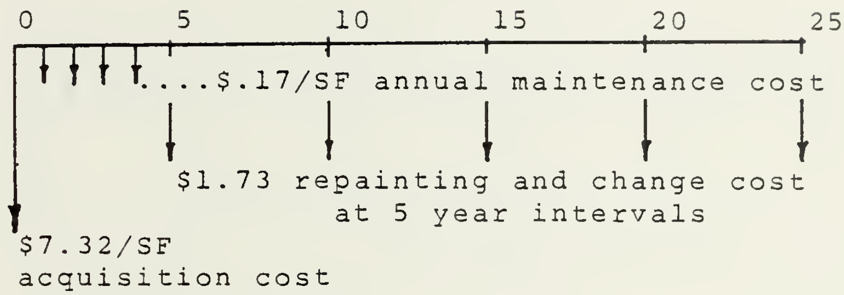



Figure C-1

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | acquisition | 7.32 | | 1.00 | 7.320 |
| 1-25 | annual maintenance | | .17 | 9.524 | 1.619 |
| 5 | Periodic | 1.73 | | .652 | 1.128 |
| 10 | repainting | 1.73 | | .405 | .701 |
| 15 | and | 1.73 | | .251 | .434 |
| 20 | change | 1.73 | | .156 | .270 |
| 25 | | 1.73 | | .097 | .168 |
| | | TOTAL NPV COST | | | $11.64 |

Table C-i

6. <u>Cash flow diagram, vinyl covered wallboard alternative</u>

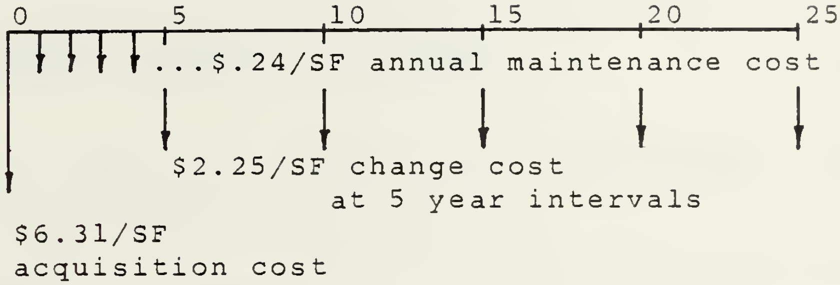



Figure C-2

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | Acquisition | 6.31 | | 1.000 | 6.31 |
| 1-25 | Annual maintenance | | .24 | 9.524 | 2.286 |
| 5 | Periodic | 2.25 | | .652 | 1.467 |
| 10 | change | 2.25 | | .405 | .911 |
| 15 | costs | 2.25 | | .251 | .565 |
| 20 | | 2.25 | | .156 | .351 |
| 25 | | 2.25 | | .097 | .218 |
| | | TOTAL NPV COST | | | $12.11 |

Table C-ii

7. <u>Discussion of results</u>

In this analysis there is an initial cost advantage of 16% in favor of the gypsum wallboard partition. When the cost over the assumed 25 year life is added and converted to

present value , the advantage shifts to the opposite side. The life cycle costs of the relocatable partition total $11.64 versus $12.11 for the gypsum wallboard partition. The difference is only 4%, close enough to prompt the designer to examine the alternatives further to test the sensitivity of various factors.

8. Possible sensitivity studies

The following additional variations of the comparison are suggested for study:

a) Decrease frequency of change from five years to seven years.
b) Increase frequency of change from five years to three years.
c) Increase frequency of painting relocatable partitions to once every three years.
d) Decrease frequency of painting to every seven years.
e) Increase cost of relocatable partitions by 20%.
f) Any reasonable combination of the above.

E. CEILING SYSTEM STUDY

1. Introduction

Ceiling systems are not always affected significantly by changes in wall partitions. Partitions that are non-load bearing are merely fitted into the space between the floor and the ceiling. Changes are then possible without disturbing the ceiling. Seismic design requirements add a new dimension by requiring that partition

walls be solidly secured to the structural grilliage above the ceiling. This means that ceilings can be installed only after wall partitions are up and that the ceiling must be torn up to move a partition. In addition, the ceiling itself must be rigidly supported to withstand earthquake disturbances. In the design studies for the New Generation Military Hospital at Travis Air Force Base, California, the architect used the concepts of life cycle cost analysis to study alternative design solutions [Ref. 19 ].

The usual ceiling specified under these requirements would be 3/4 inch acoustical tile cemented to 5/8 inch gypsum board which is firmly secured to the structure. This system is relatively inexpensive initially but has high replacement costs. To simplify replacement an alternative re-usable ceiling system was developed. This system was designed to be feasible in any room of 64 square feet or larger and is 90% re-usable on the average.

2. Assumptions

The "system" ceiling is based on 4' x 4' units while the typical ceiling is based on 4' x 8' units.

Prices are based on dollars per square foot.

The change frequency has been set at two years.

First costs have been estimated
2.25/SF for conventional ceiling
3.00/SF for re-usable ceiling

Change costs have been estimated

2.65/SF for conventional ceiling

1.00/SF for re-usable ceiling

Neither ceiling interacts with partitions.

Lighting and maintenance considerations are equal for the two ceilings.

The illustrative building life of 25 years and DOD discount rates will again be applied.

3. <u>Cash flow diagram, conventional ceiling system alternative</u>

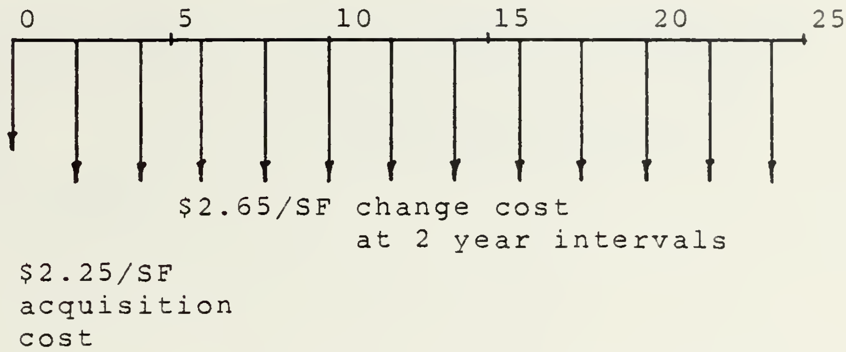



Figure C-3

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | Acquisition cost | 2.25 | | 1.00 | 2.250 |
| 2 | Change | 2.65 | | .867 | 2.298 |
| 4 | cost | 2.65 | | .717 | 1.900 |
| 6 | | 2.65 | | .592 | 1.569 |
| 8 | | 2.65 | | .489 | 1.296 |
| 10 | | 2.65 | | .405 | 1.073 |
| 12 | | 2.65 | | .334 | .885 |
| 14 | | 2.65 | | .276 | .731 |
| 16 | | 2.65 | | .228 | .604 |
| 18 | | 2.65 | | .189 | .501 |
| 20 | | 2.65 | | .156 | .413 |
| 22 | | 2.65 | | .129 | .342 |
| 24 | | 2.65 | | .107 | .284 |
| | | TOTAL NPV COST | | | $14.15 |

Table C-iii

4. Cash flow diagram, re-usable ceiling system alternative

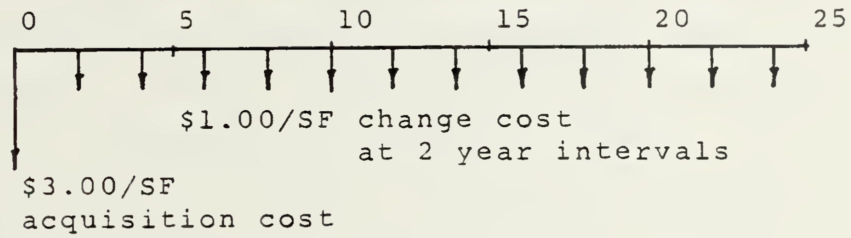



Figure C-4

| PROJ YEAR | COST ELEMENT | AMOUNT ONE-TIME | AMOUNT RECURRING | DISCOUNT FACTOR | DISCOUNTED COST |
|---|---|---|---|---|---|
| 0 | Acquisition | 3.00 | | 1.00 | 3.000 |
| 2 | Change | 1.00 | | .867 | .867 |
| 4 | cost | 1.00 | | .717 | .717 |
| 6 | | 1.00 | | .592 | .592 |
| 8 | | 1.00 | | .489 | .489 |
| 10 | | 1.00 | | .405 | .405 |
| 12 | | 1.00 | | .334 | .334 |
| 14 | | 1.00 | | .276 | .276 |
| 16 | | 1.00 | | .228 | .228 |
| 18 | | 1.00 | | .189 | .189 |
| 20 | | 1.00 | | .156 | .156 |
| 22 | | 1.00 | | .129 | .129 |
| 24 | | 1.00 | | .107 | .107 |
| | TOTAL NPV COST | | | | $7.49 |

Table C-iv

## 5. Discussion of results

The life cycle cost analysis demonstrates that there is considerable advantage to taking the design time necessary to develop a re-usable ceiling. In the original study the architect investigated many variations from the base case such as increasing the estimated cost of changing the re-usable ceiling, decreasing change frequency to five years, and a combination of both of these. Even in the extreme case of a change at ten year intervals and with change costs increased 50%, the re-usable ceiling still has a life cycle cost advantage.

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